INFRARED REFLECTANCE SPECTRA OF

IGNEOUS ROCKS, TUFFS AND RED

SANDSTONE FROM 0.5 TO 22 MICRONS


By

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ABSTRACT

Total reflectance measurements on a number of igneous rocks and other minerals indicate that reststrahlen features may be of use as a remote probe into the nature of the surface of the moon and planets. Varying particle size introduces effects such as reduced spectral contrast and in some cases a new feature that could lead to confusion in identification unless particle size is known. Short wavelength reflectance measurements are seen to offer a method of determining particle size by remote measurements.

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## INTRODUCTION

Of basic interest to a program of planetary exploration is the surface composition and condition of the planetary body. Infrared analysis offers a promising tool to carry out such an investigation. Although thermal emission analysis seems to be the only feasible method of study from an orbiting vehicle, the present study has involved reflection measurements on igneous rocks and other minerals thought likely to provide basic information about planetary surfaces. The experimental arrangement utilized in these investigations measured reflectance over $2\pi$ steradians with little heating of the specimen. This indirect, but accurate method of determining emissivity, permitted higher spectral resolution than is possible in thermal emission unless the specimen is very hot.

## EXPERIMENTAL PROCEDURE

An attempt has been made during sample preparation and measurement, to approximate the natural state of the materials under investigation. Solid surfaces were not polished but were used in a freshly fractured state. The samples with smaller particle sizes were prepared by crushing and then sifting through a series of graded sieves. In this way samples were prepared with particle sizes ranging from 2-4 mm to less than 0.038 mm. Most of the plotted curves contain results for four particle sizes, i.e., a solid sample, 1-2 mm, 0.105-0.25 mm, and less than 0.038 mm. For many samples, measurements were also made at intermediate sizes, but these four sizes were found to be representative and results pertaining to other sizes have been omitted to avoid overcrowding of the composite figures.

In the 0.5-2.5 micron wavelength region, the total reflectance of the specimens was measured with a Beckman DK2A spectrophotometer equipped with a total reflectance attachment. Measurements from 2.5-22 microns were carried out on a Cary Model 90 double-beam spectrophotometer equipped with the prototype total reflectance attachment described by White (1).

RESULTS

It might be recalled that igneous rocks are often described by terminology based on the $SiO_2$ content. $SiO_2$ is considered the "acidic" oxide in these rocks, which may be divided into the following categories:

| | | | |
|---|---|---|---|
| ultrabasic | less than 45% | $SiO_2$ | - e.g. Dunite |
| basic | 45-53% | $SiO_2$ | - e.g. Basalt |
| intermediate | 53-65% | $SiO_2$ | - e.g. Syenite |
| acidic | above 65% | $SiO_2$ | - e.g. Granite |

Acidic rocks are rich in light minerals such as quartz and potash feldspar, while basic rocks are richer in ferromagnetic materials.

Figs. 1 to 5 contain reflectance measurements for four different igneous rocks which range from the acidic rock, granite, to the ultrabasic, dunite. These spectra indicate the changes in reflectance as the material is reduced from a solid, freshly fractured sample to a sample in which the particles are below 40 microns in diameter.

It has been suggested that tektites originate from the lunar surface. Fig. 5 displays the reflectance spectrum of a S.E. Asia tektite while Figs. 6, 7, and 8 provide the spectra of two tuffs and a red sandstone. The tuffs are quite similar at shorter wavelengths but Tuff #6 shows reststrahlen features at 9 microns and 20 microns that are absent in the other tuff.

Fig. 9 to Fig. 12 are composite curves constructed from the respective measurements on the first four materials listed in the figures. These composites are collated for various particle sizes. These curves provide an idea of the complexity introduced when several materials lie within the field of view of the spectrometer.

In order to verify the actual spectrum for composite samples, Fig. 13 displays the reflectance spectra obtained when equal parts by volume of the four igneous rocks, granite, basalt, serpentine and dunite were mixed. These curves follow closely the spectra predicted from composites based on the measurements of the individual materials. A solid sample composed of these four rocks has not yet been constructed.

Fig. 14 is a composite figure that shows the 7-15 micron region for the various samples. This display is primarily intended to show an effect noticed in this work. For many materials, especially quartz, granite, dunite, the tuffs and the sandstone, when the particle diameter is reduced below 100 microns, a new reflectance feature begins to appear at longer wavelengths. For a material such as quartz, when the particle diameter is reduced below 40 microns, this peak is stronger than the original reststrahlen feature. For four of the spectra a curve is included that describes the spectrum when the particle size was reduced considerably below 40 microns by means of extended grinding. For quartz, the new feature continued to be enhanced while the other reststrahlen features continued to diminish. For sandstone and dunite, the new features remained approximately constant.

In order to test if this effect was due to selective filtering, Figs. 15 and 16 contain the reflectance spectra of high purity fused natural quartz and that of synthetic quartz. The persistence of the long wavelength feature in the finely powdered sample for both of these materials indicates that the effect is not one of selective filtering. It may be noted that the synthetic quartz, due to its manufacturing process, shows much stronger water of hydration features at 6.35, 2.7 , 2.2 and 1.4 microns than does the fused G.E. quartz, while the reflectance for the fused quartz is much higher in the shorter wavelengths at small particle sizes.

## CONCLUSIONS

This work confirms the general observation that the contrast of the reststrahlen features decreases as the particle size of the sample is reduced. Figs. 1-8 and 15 and 16 show this general effect. The sharpest decrease in reflectance at the reststrahlen wavelengths usually occurs between the solid sample and that in which the particle size is between 1-2mm. The decrease is not too marked between a 1-2 mm sample and that with a particle size of 0.105 - 0.250 mm, but this is often followed by another sharp decrease in reflectance when the particle size is reduced below 38 microns. Since there is a considerable likelihood that the lunar and martian surfaces are quite dusty, spectral contrast will probably be rather low.

One exception noted is dunite where there is a rise in the reflectance at the reststrahlen wavelength when the particle size is reduced from 1 - 2 mm down to 0.105 - 0.250 mm. This may be a selective filtering effect.

This work also confirms the observation (2) that the fundamental Si-O vibration near 10 microns shifts with the type of igneous rock. The composite Fig. 11 shows this shift. For granite, an acidic rock, and for quartz, this feature occurs near 9 microns, while for the ultrabasic material dunite, this peak occurs near 10.7 microns. This effect has been suggested as a test for the general type of material occurring on the surface of the moon. Our observations confirm the possibility but suggest that the situation is highly complex, especially when in actual observation from earth by a telescope or from an orbiting spacecraft, more than one sample will lie in the field of view of the spectrometer, and different particle sizes will be present for each rock. Fig. 15 shows the effect for composite samples of various igneous rocks when the particles are of one size, alone. Such composites suggest that the Si-O shift may be washed out by the presence of several igneous rocks with various particle sizes in the spectrometer's field of view. Obviously this problem would be greatly reduced in analysis performed after soft landing.

The effect which produces a new reflectance feature when the particle size of many rocks is reduced below 100 microns will also complicate this acidic vs. basic test. As Fig. 14 showed, a finely powdered granite dust will appear quite similar to a basic rock, and if a basic rock were also present, the composite curve would appear to peak at the longer wavelengths indicative of an ultra-basic surface. The average shift toward longer wavelengths for the materials measured in this work was 2.3 microns, almost identical with the total shift of the Si-O vibration between acidic and ultra-basic materials. A finely powdered acidic surface might be classified as dunite. This mistaken identity might be avoided if a scan is also made in the 1-4 micron region of the spectrum where the much higher reflectance of finely powdered samples might help distinguish the dust from solid samples.

On almost all of the curves will be noted the water of hydration features at 6.35, 2.7, 2.2 and 1.4 microns. In some cases, such as in tektites, this amount presently lies beyond the limits of geological analysis. Work has begun to calibrate these features for use as a sensitive probe of waters of hydration on planetary surfaces. The water of hydration features in tektites is the smallest observed in any naturally occurring material.

A brief analysis of the samples used prepared by Dr. Louis Walter is given in Table 1.

## REFERENCES


1 White, J. U., New Method of Measuring Diffuse Reflectance in the Infrared, JOSA 54, 1332, (1964).

2 e.g. Lyon, R. J. P., Econ. Geol. 60, 715 (1965).

## ACKNOWLEDGEMENTS

We would like to acknowledge the assistance of P. Lowman and L. Walter of the Goddard Space Flight Center for providing most of the samples and for their many helpful discussions. We also wish to acknowledge the constant and careful effort of H. Keegan and V. Weidner of the National Bureau of Standards in performing all of the measurements from 2.5 - 22 microns. Our special thanks, also, to L. Horrell for his careful reduction of the data.

## TABLE I

| Sample | Brief Description |
| --- | --- |
| NAA Standard Granite | Quartz, feldspar and pyroxene. Contains plagioclase and orthoclase |
| NAA Standard Oregon Serpentine | Magnesium-rich, contains about 5% opaque material, probably chromite |
| NAA Standard Oregon Basalt | Very little glass, mostly crystals of feldspar and some pyroxene |
| Dunite, Mereufelder Moar | Magnesium (variety forsterite) |
| Tektite, S.E. Asia | Glass containing approximately 70% $S_1O_2$. Not visibly strained |
| Tuff #62-13 | Very fine grained, mostly glass, much sanidine, some quartz |
| Tuff #6 | 50% quartz plus feldspar (mostly quartz), 50% glass, much quartz |
| Red Sandstone | Much iron oxide, .105 to .250 mm fragments are agglomerates of particles of 40 micron size, contains Calcite |
| G.E. 106 Fused Quartz | Less than .038 mm good glass, 0.105 to 0.250 mm good glass, no strain |
| Dynasil Fused Silica | Less than 0.038 mm mostly glass, some quartz, 0.105 to 0.250 mm, all glass, no quartz, no strain |

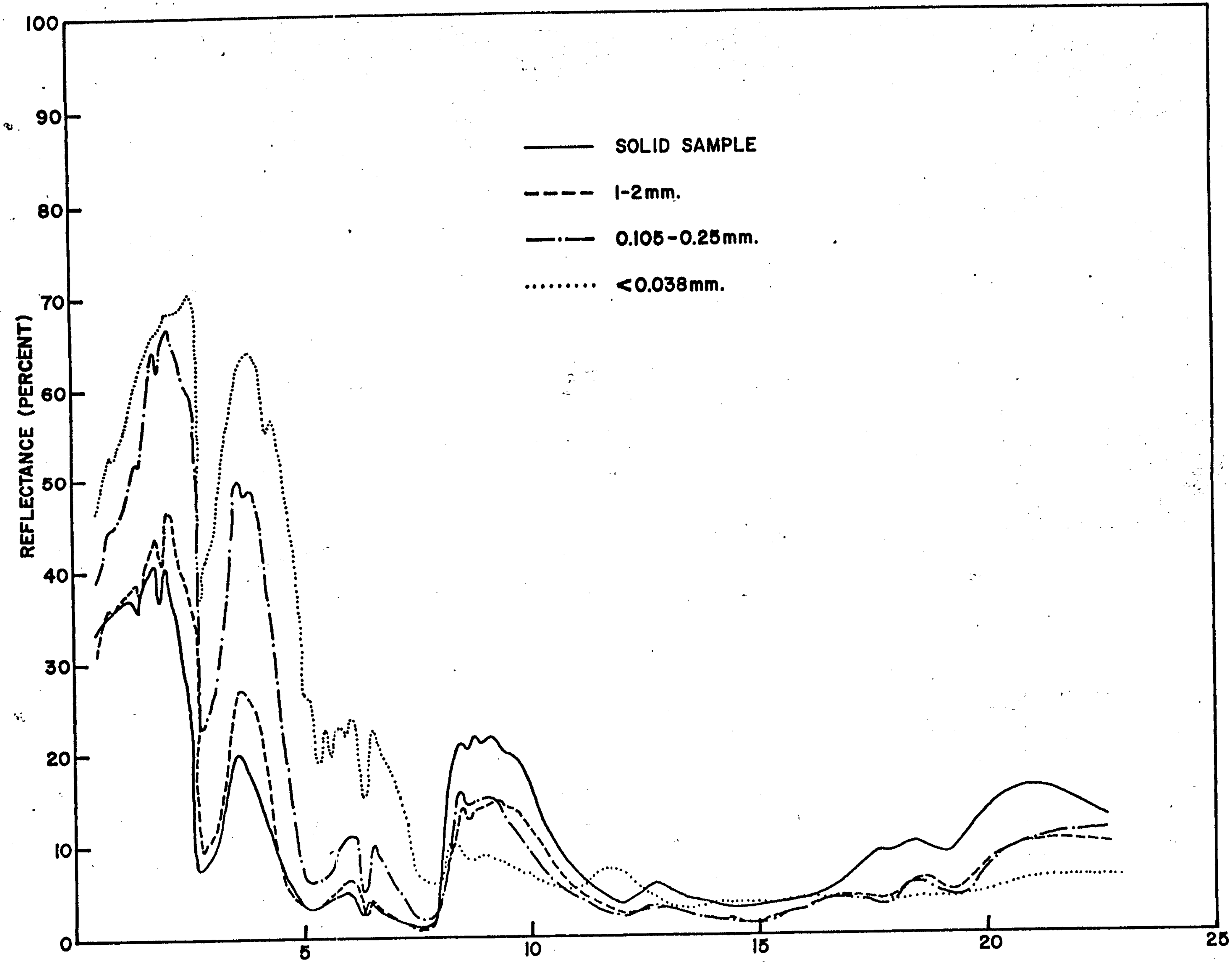
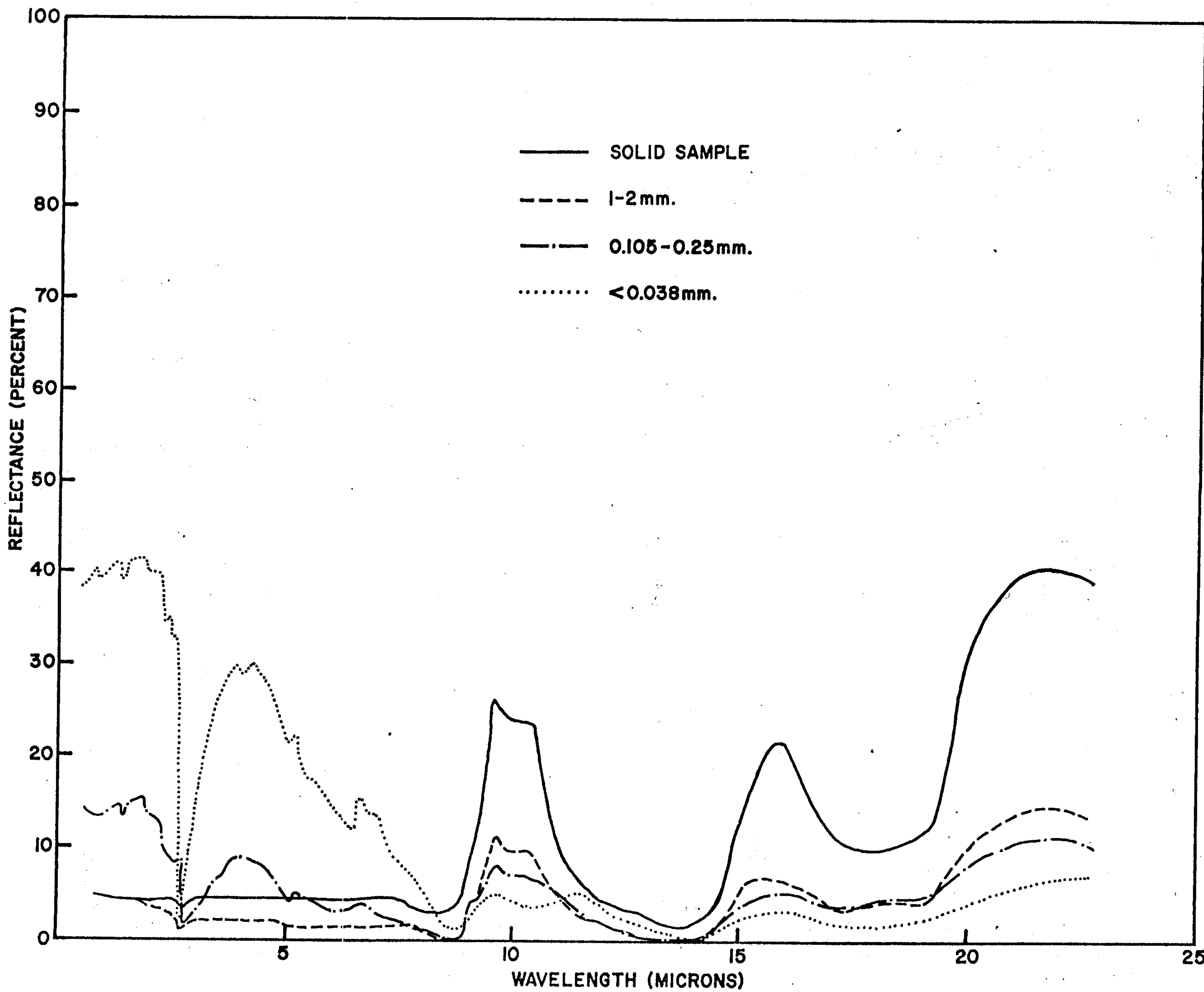

SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
0
10
20
30
40
50
60
70
80
90
100
5
10
15
20
25
WAVELENGTH (MICRONS)

Fig 1



SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
WAVELENGTH (MICRONS)
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90
100
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15
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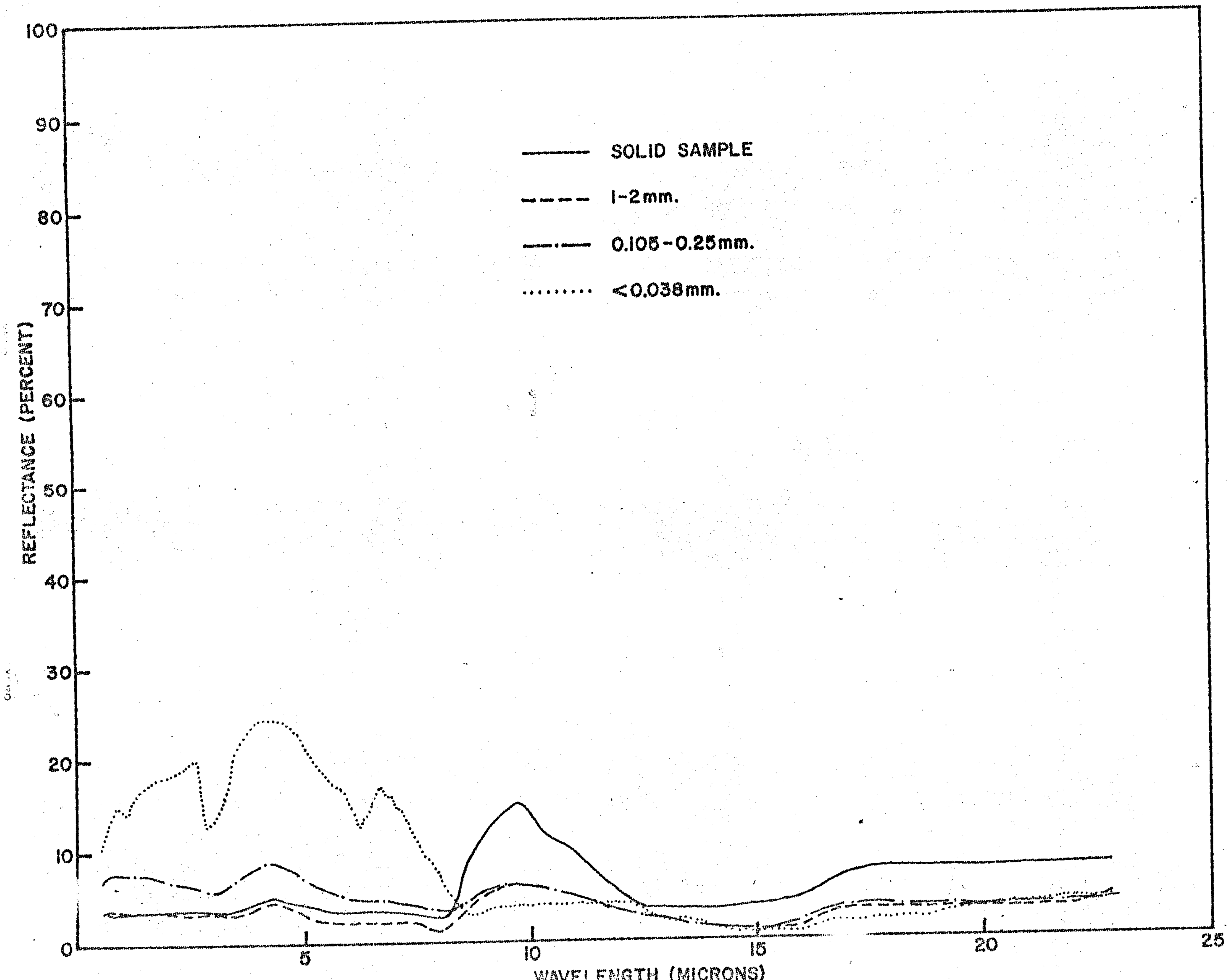
25


Fig 2


SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
100
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0
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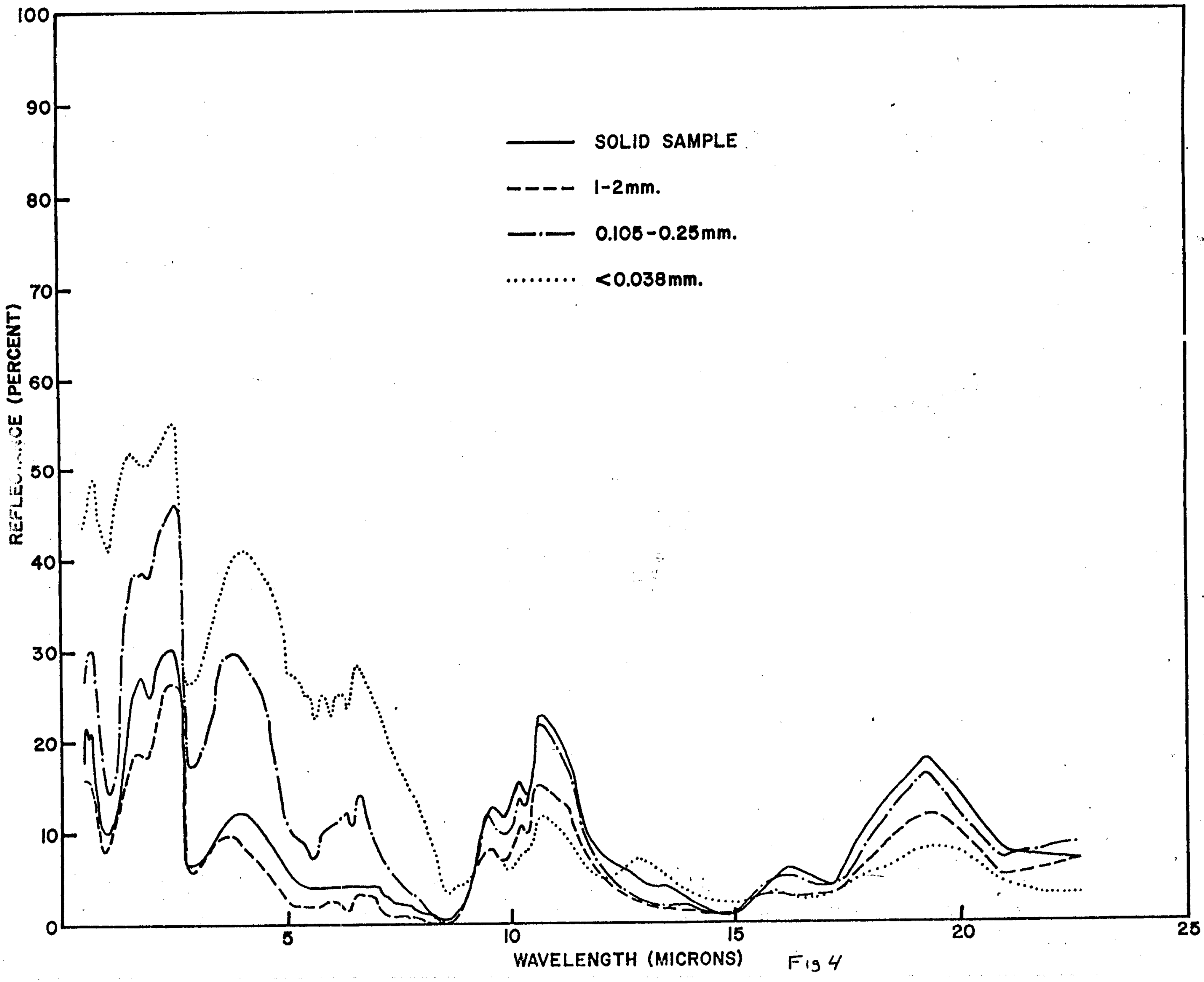
15
20
25
WAVELENGTH (MICRONS)

3


SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLEC...CE (PERCENT)
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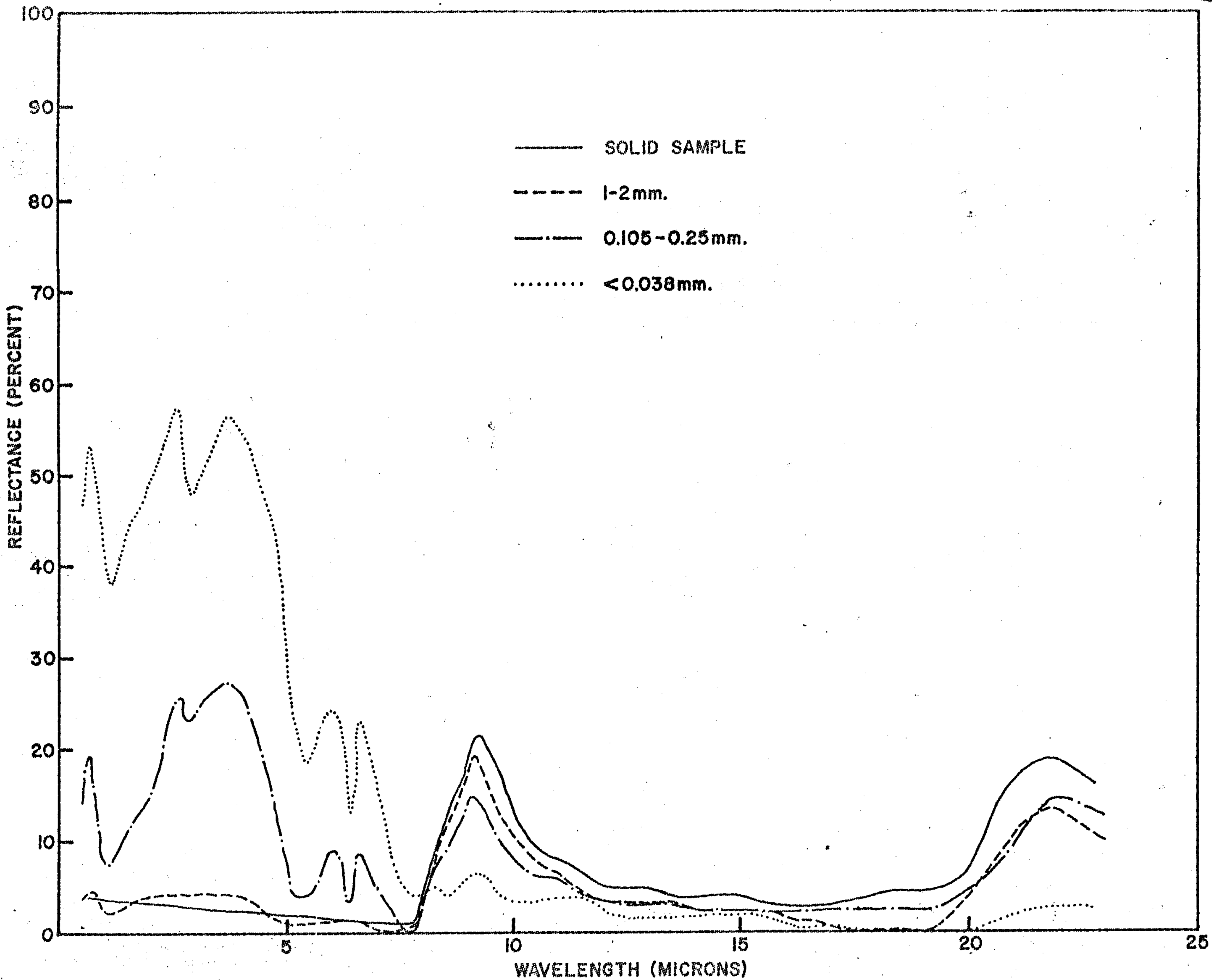
25
WAVELENGTH (MICRONS)

Fig 4



SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
WAVELENGTH (MICRONS)
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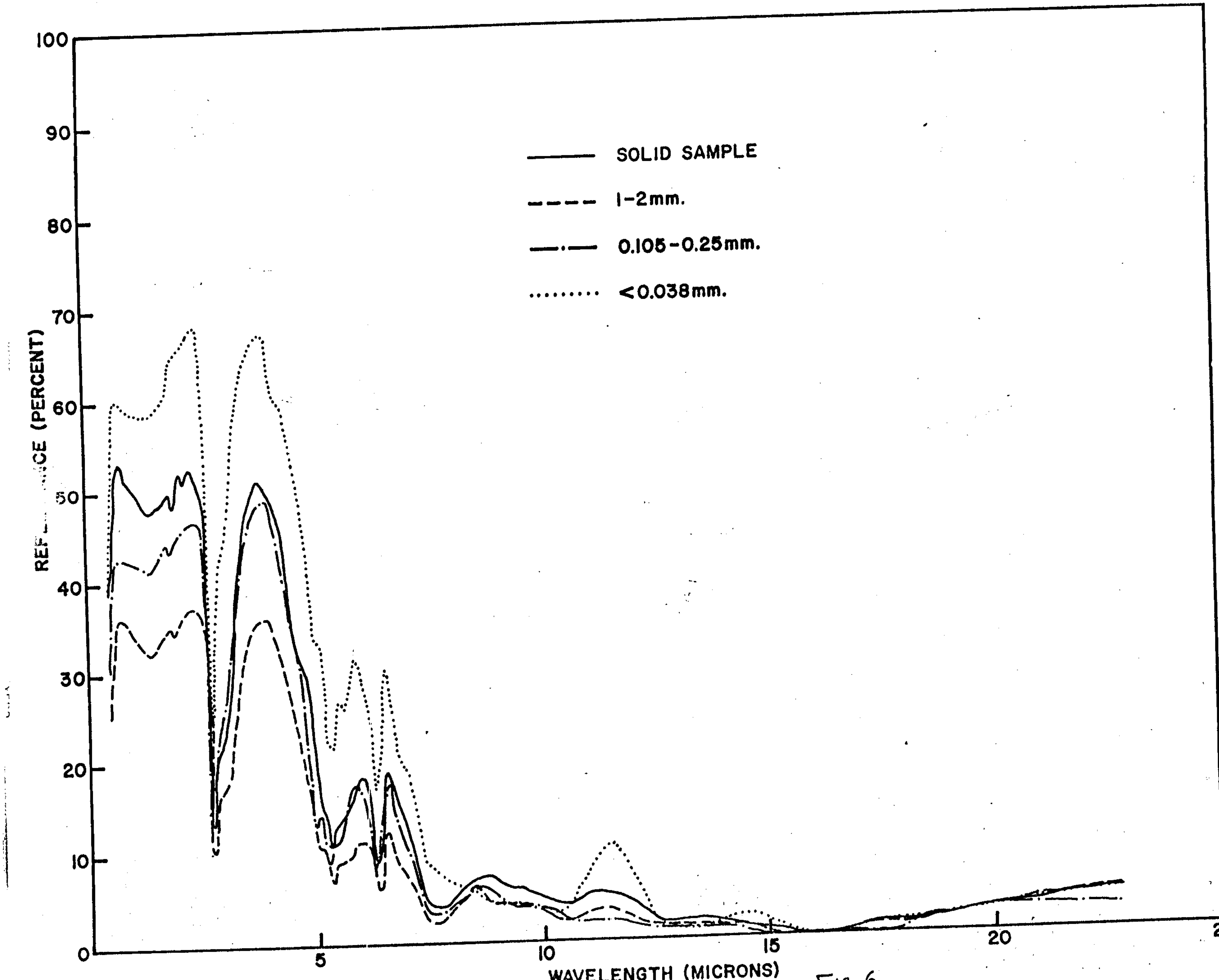
Fig 5.


SOLID SAMPLE
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0.105-0.25mm.
<0.038mm.
100
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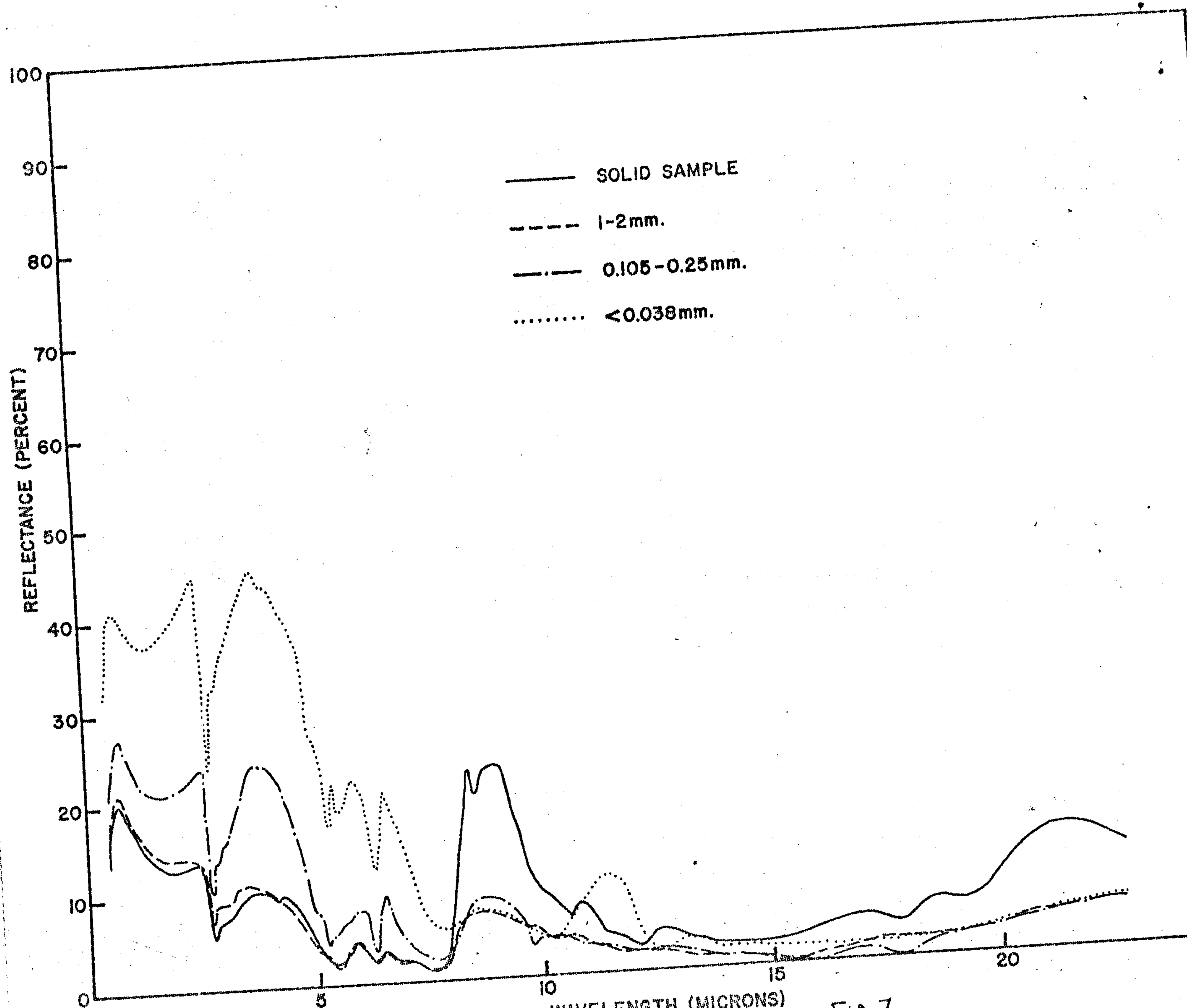
WAVELENGTH (MICRONS)

Fig 6.


SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
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REFLECTANCE (PERCENT)
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20
WAVELENGTH (MICRONS)

Fig 7

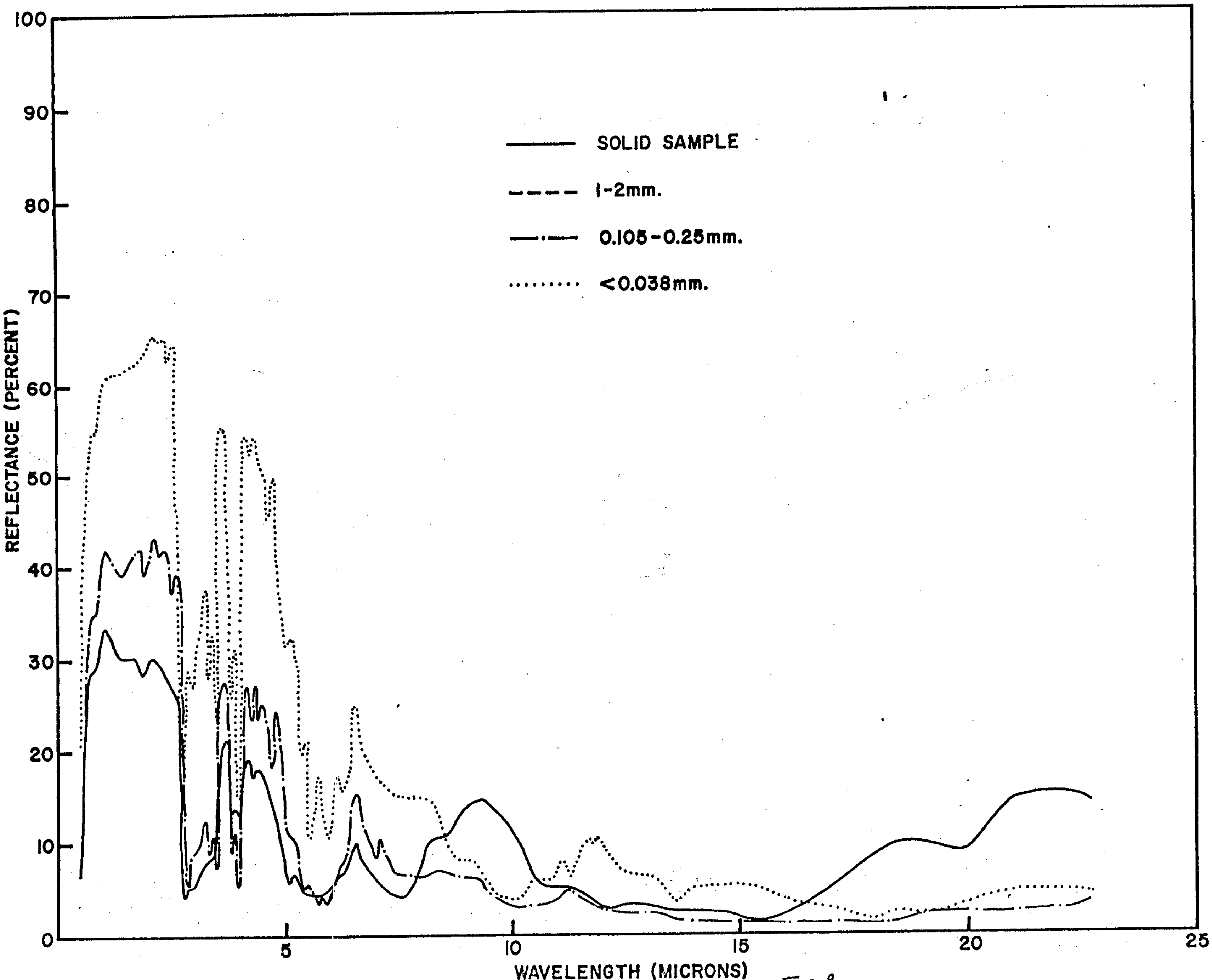
SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
WAVELENGTH (MICRONS)
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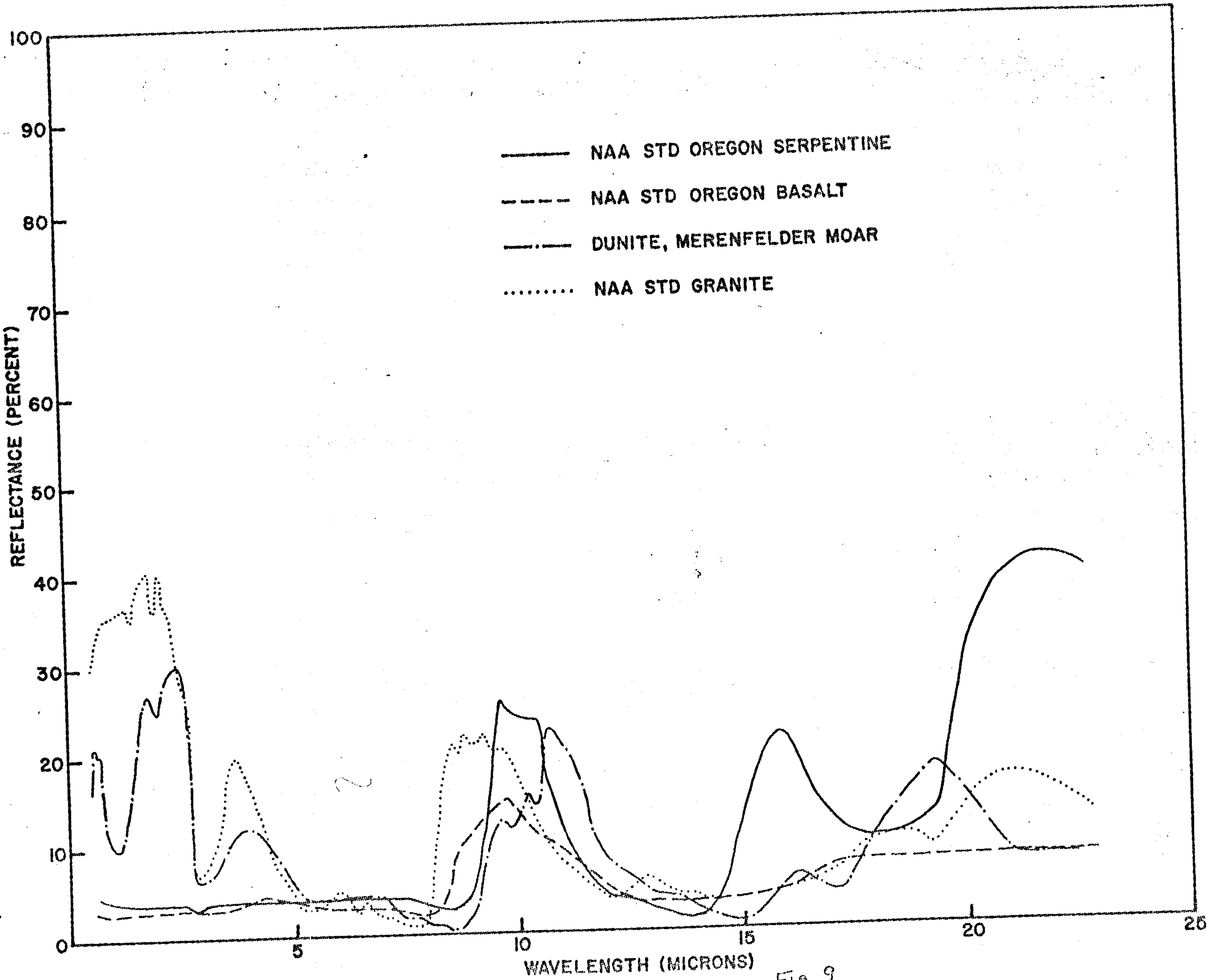
Fig 8


NAA STD OREGON SERPENTINE
NAA STD OREGON BASALT
DUNITE, MERENFELDER MOAR
NAA STD GRANITE
REFLECTANCE (PERCENT)
100
90
80
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WAVELENGTH (MICRONS)
Fig 9

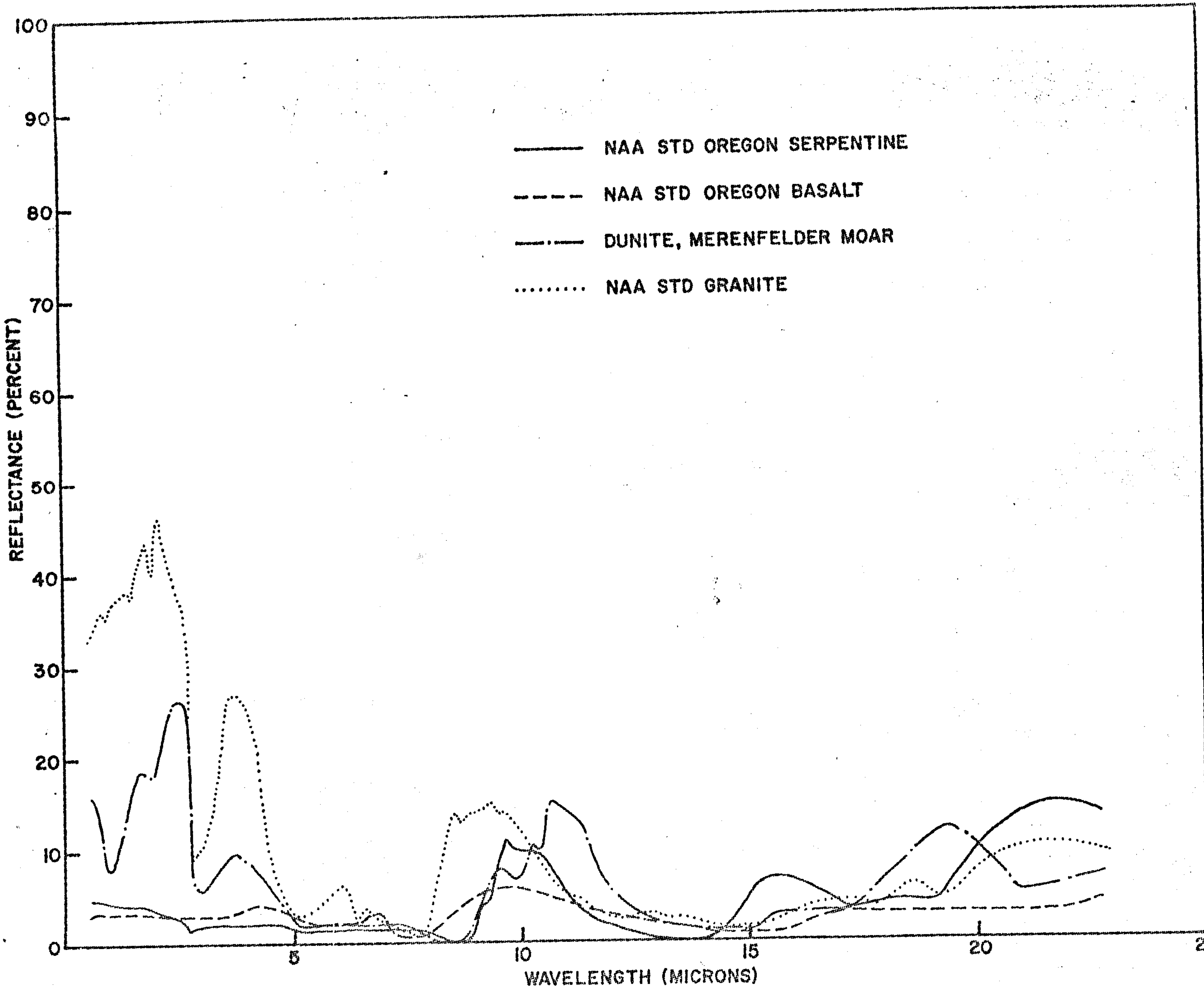
NAA STD OREGON SERPENTINE
NAA STD OREGON BASALT
DUNITE, MERENFELDER MOAR
NAA STD GRANITE
REFLECTANCE (PERCENT)
WAVELENGTH (MICRONS)
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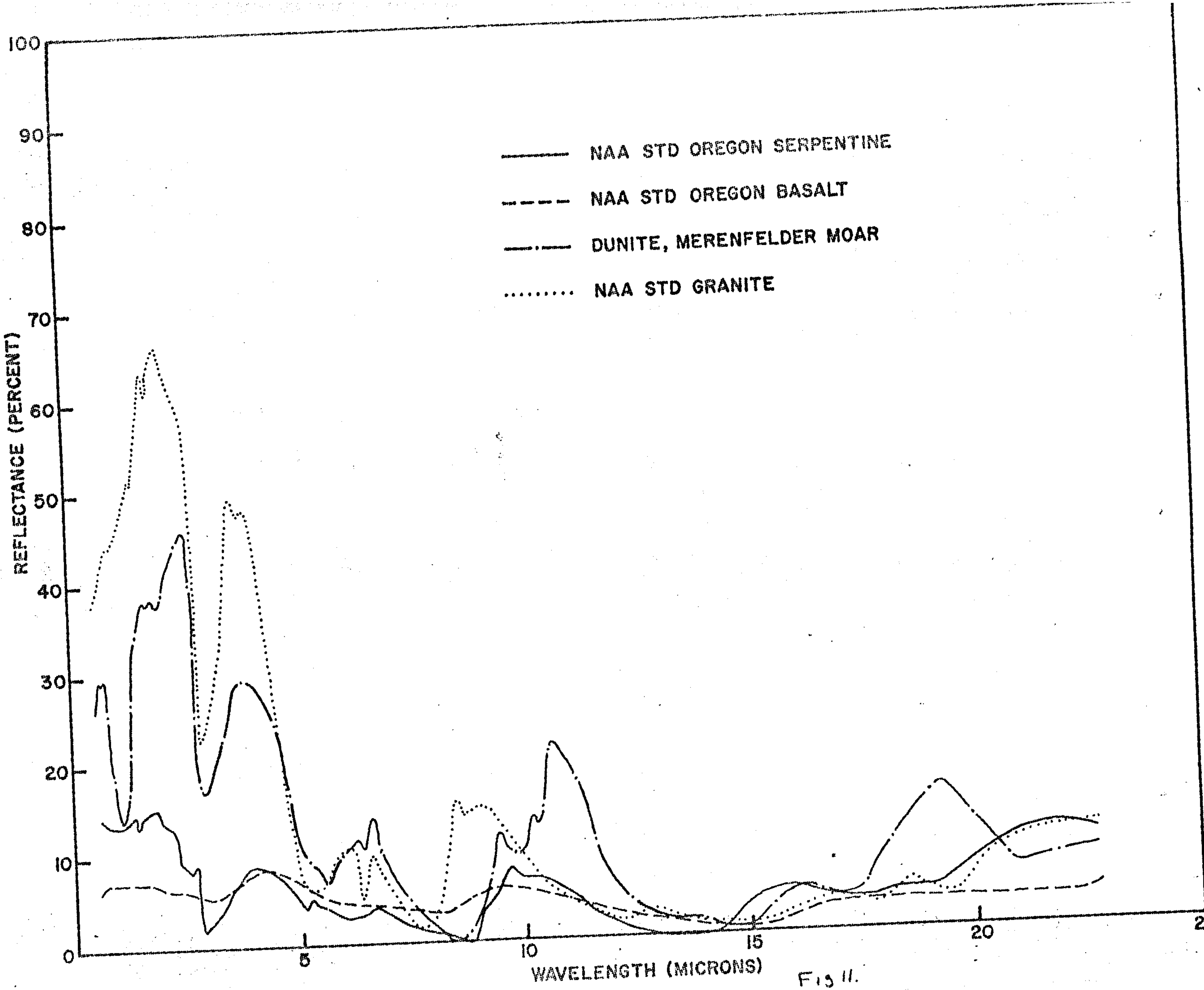
Fig 10


NAA STD OREGON SERPENTINE
NAA STD OREGON BASALT
DUNITE, MERENFELDER MOAR
NAA STD GRANITE
REFLECTANCE (PERCENT)
100
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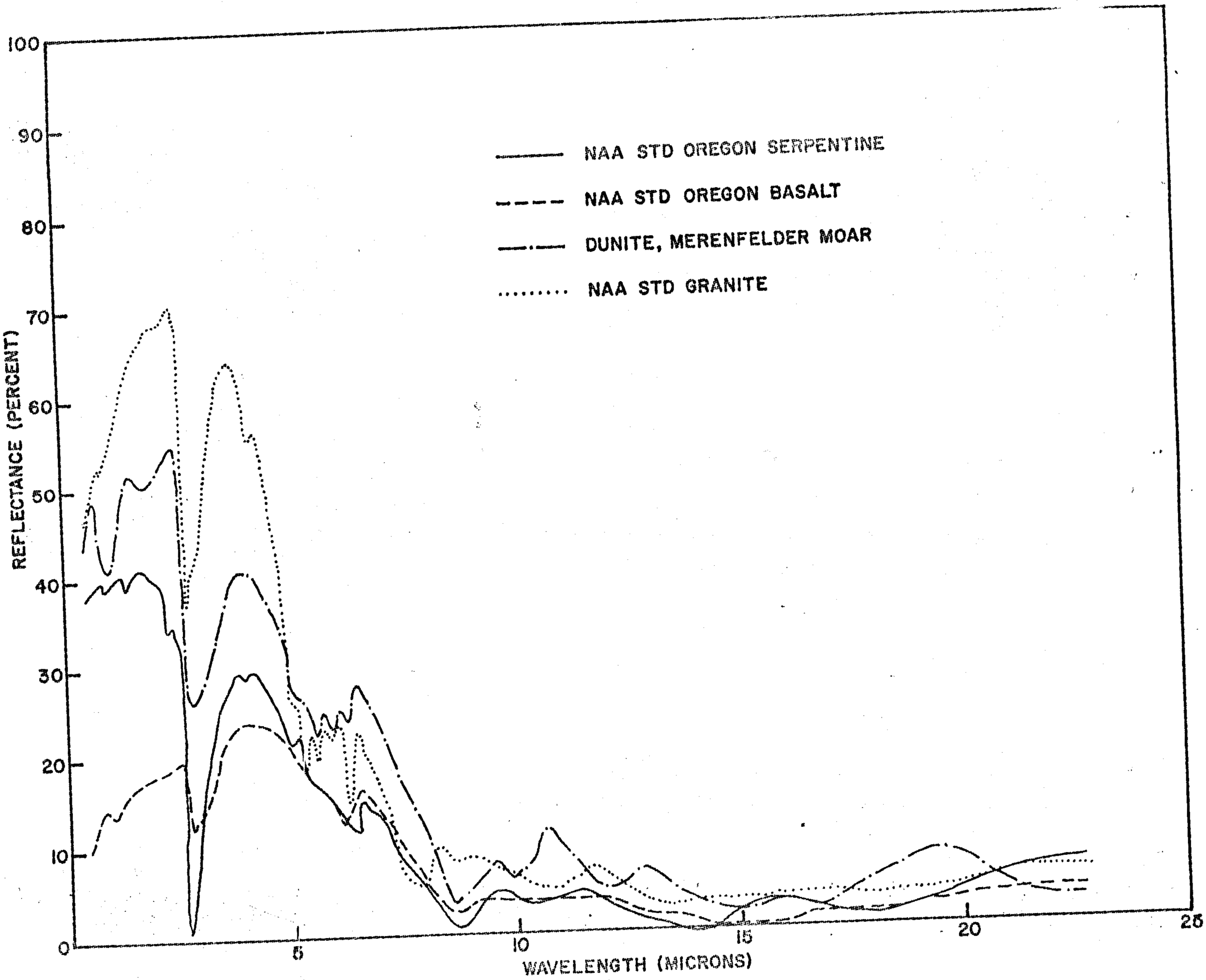
WAVELENGTH (MICRONS)

Fig 11.


NAA STD OREGON SERPENTINE
NAA STD OREGON BASALT
DUNITE, MERENFELDER MOAR
NAA STD GRANITE
REFLECTANCE (PERCENT)
100
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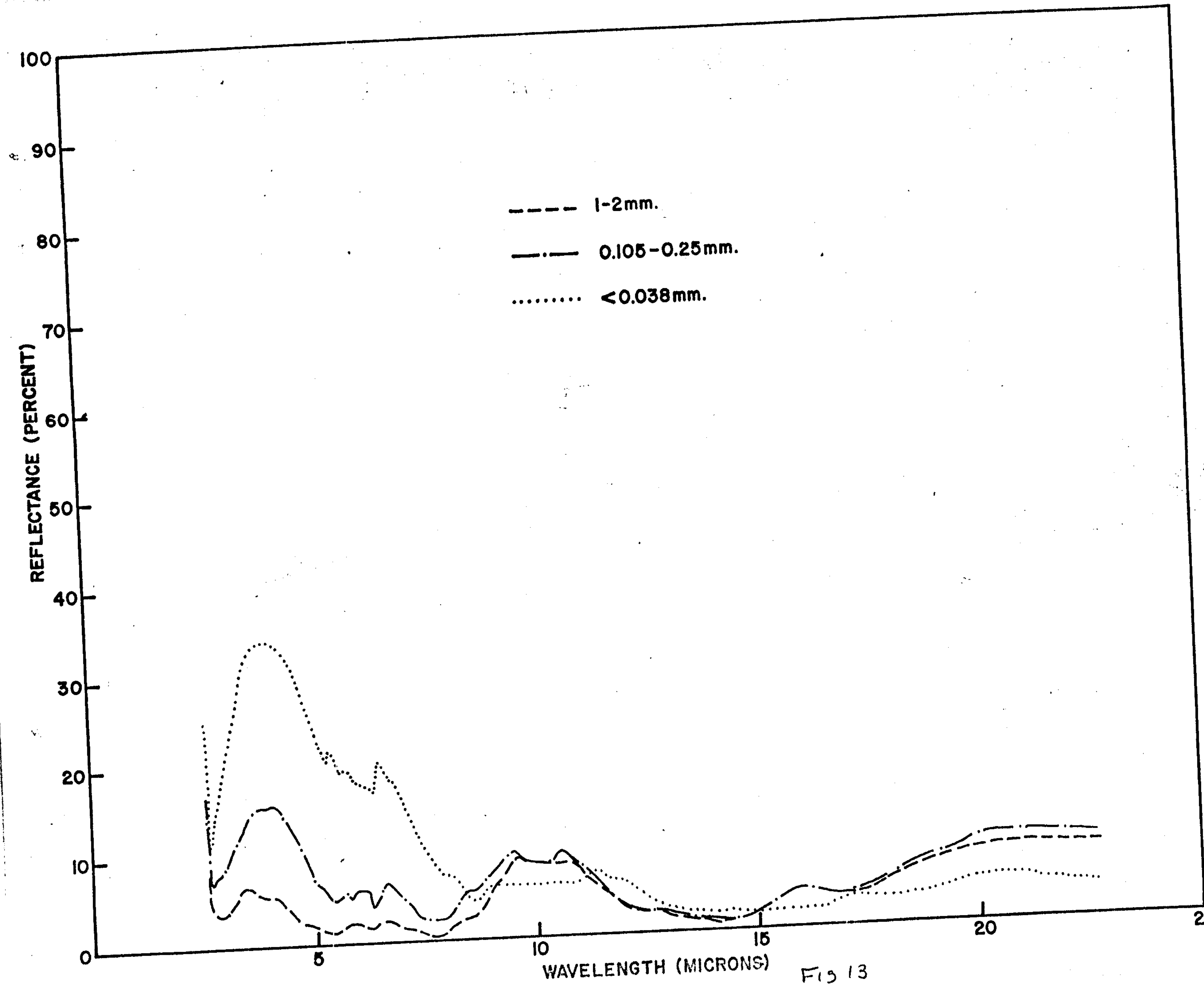
WAVELENGTH (MICRONS)

Fig 12.



1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
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25
WAVELENGTH (MICRONS)


Fig 13

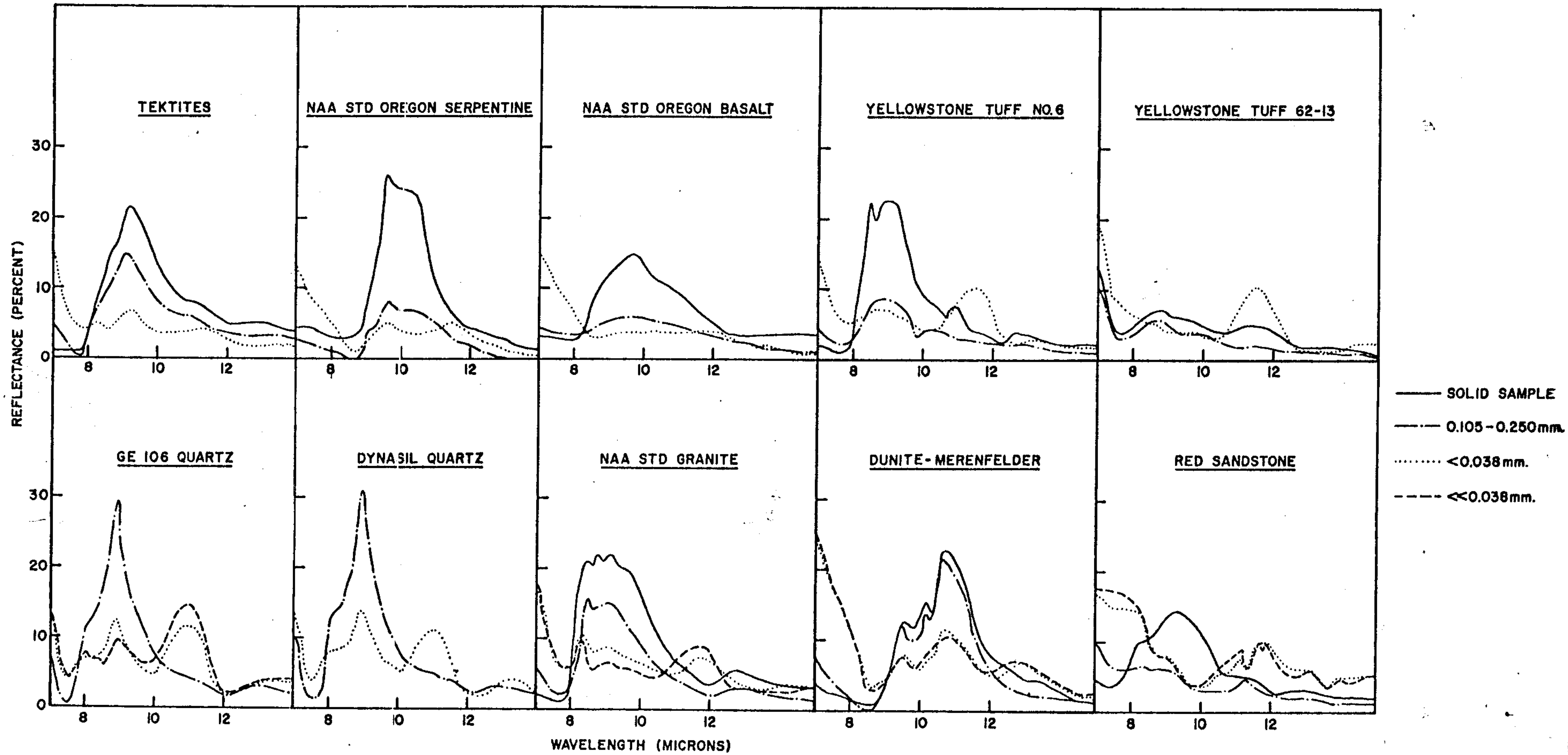
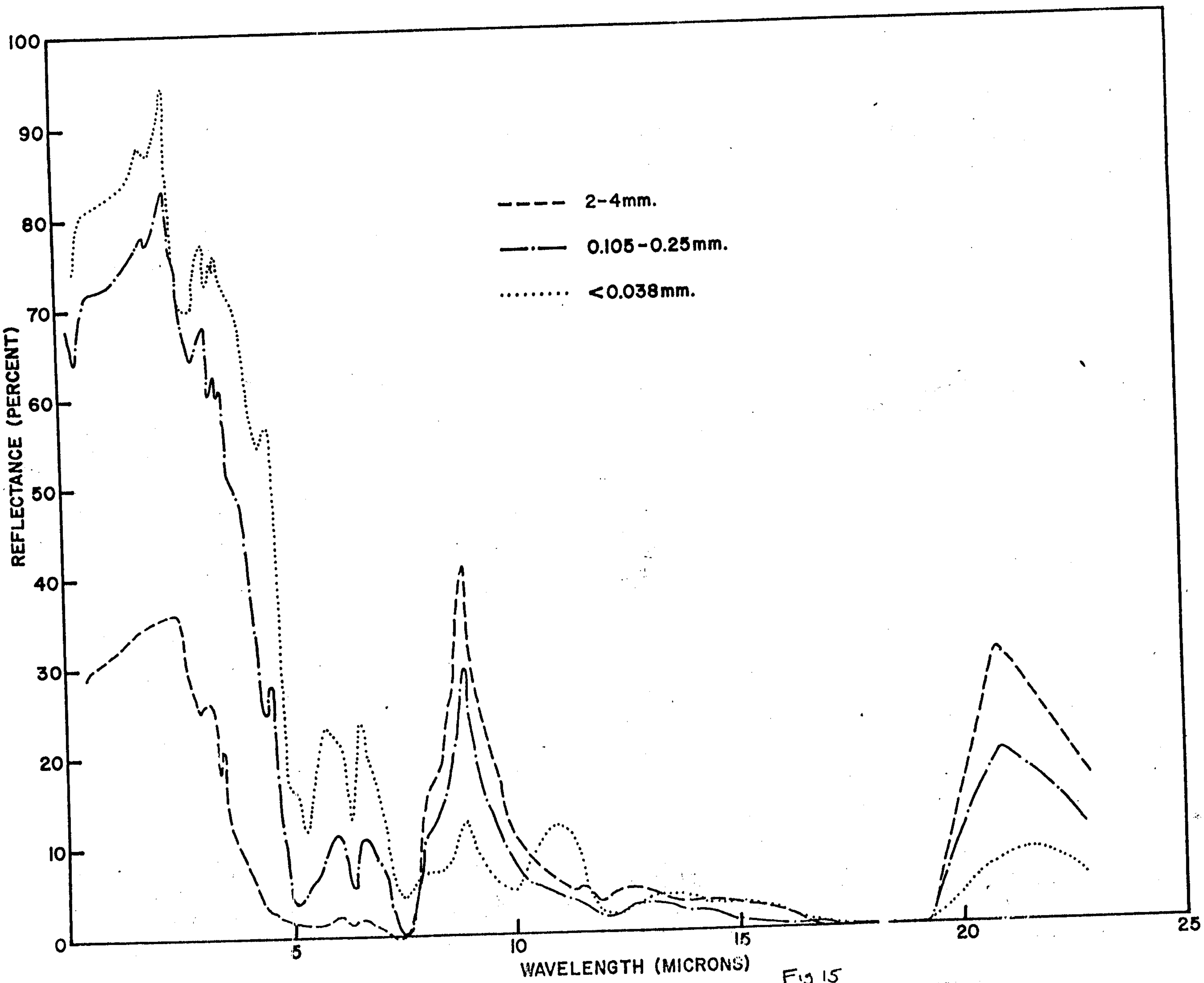

TEKTITES
NAA STD OREGON SERPENTINE
NAA STD OREGON BASALT
YELLOWSTONE TUFF NO.6
YELLOWSTONE TUFF 62-13
GE 106 QUARTZ
DYNASIL QUARTZ
NAA STD GRANITE
DUNITE-MERENFELDER
RED SANDSTONE
REFLECTANCE (PERCENT)
WAVELENGTH (MICRONS)
0
10
20
30
8
10
12
SOLID SAMPLE
0.105-0.250mm.
<0.038mm.
<<0.038mm.

Fig 14



REFLECTANCE (PERCENT)
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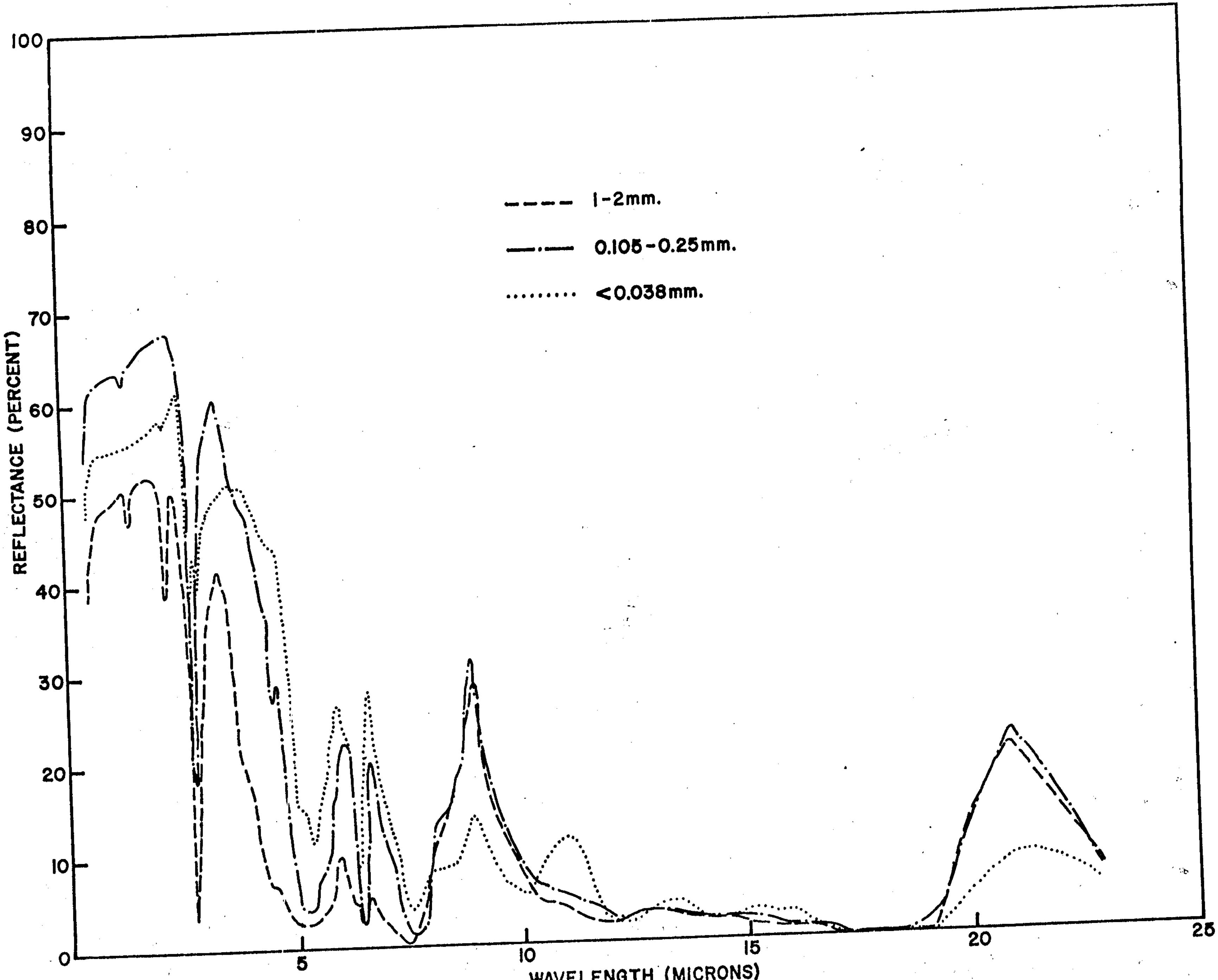
WAVELENGTH (MICRONS)
2-4mm.
0.105-0.25mm.
<0.038mm.


Fig 15


REFLECTANCE (PERCENT)
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25
WAVELENGTH (MICRONS)
1-2mm.
0.105-0.25mm.
<0.038mm.

Fig 16